Q: Why Do Certain Terms in The Language of Science Cause So Much Confusion?

By Matt Bobrowsky

A: Teaching and learning require language, and in science, the language needs to be quite precise. Once the vocabulary is clear, teachers can explain concepts and ask students questions, and students can understand, participate in discussions, and ask their own questions.

Language in the science classroom includes both technical/scientific terms and non-scientific words. There are three situations that cause difficulty: (1) when a term has both a scientific and non-scientific meaning, and the two are different; (2) when students have misconceptions that the teacher is unaware of, and (3) when teachers have a misconception about the meaning of a scientific term or about how scientists do their work.

“THEORY”

Some problematic words include theory, law, and hypothesis. The term theory is probably the most common example where understanding is hampered by multiple meanings. In popular usage, theory is used to mean something dreamed up to explain an observation or event. We often hear someone say, “It’s my theory that…” but that’s almost the opposite of what scientists mean by that word. A scientific theory, like cell theory or atomic theory, is a group of related ideas that has been extensively tested. It is based on observations, logical reasoning, and calculations. It produces explanations for a broad range of phenomena and makes predictions, allowing it to be tested.

As an example of the broad explanatory power of a theory, consider atomic theory. Once you understand that everything is made of atoms, you can then understand phenomena such as air pressure, heat, and sound waves. How cool is it that one theory can explain such a diversity of phenomena?! That’s why theories are so important—and powerful—in science. Most theories are bolstered by tremendous amounts of supporting evidence. And many theories are also facts, atomic theory being one example.

Now you can see why it’s so bad when someone refers to a scientific idea as “only a theory.” The word “only” in this phrase shows a major misunderstanding about the very high stature of scientific theories. A successful theory is about as high as you can get on the confidence scale in science, given the huge amount of evidence supporting most theories. A particularly egregious example of “only a theory” occurs when someone says, “evolution is only a theory.” Here’s why: This shows both a misunderstanding of theory as well as a misunderstanding of biological evolution. Whoever makes such a statement doesn’t understand that there is both fact and theory related to evolution. That species change over time is an observed fact. It is observed both in the lab and in nature. The “theory” part deals with the mechanisms of evolution, for example, natural selection as an explanation for why species change. Also, sometimes people refer to Darwin’s 1859 book as “Origin of Species.” But the title is much longer than that, the first part of
which is: “On the Origin of Species by Means of Natural Selection....” Darwin (and others) had observed that new species arose. Then he (and Alfred Wallace) suggested natural selection as a theory to explain the appearance of new species. So it's natural selection that is the theory, not the fact of evolution itself. And, if you understand how evolution works, you realize that it MUST occur. It cannot be avoided.

**“LAW”**

Another terminology misconception is evident if someone says that when a theory is proved, it becomes a law. Nope. Theories do not grow up to become laws. A law does not provide an explanation as a theory does, but rather is a description of what we observe or can expect to observe. (You can see more discussion of the difference between theories and laws by following the link in Online Resources.) Newton’s law of gravity specifies the force between two bodies and tells you to expect a dropped apple to fall, but it doesn’t really explain. Laws are often expressed mathematically, as are Newton’s laws of motion and law of gravity.

**Law** is another word that has both scientific and colloquial meanings. I’ve just described the scientific use of the term, and you already know the everyday use of the word, as in laws passed by local or state legislators (law makers). Those laws are different because they are not laws of nature and can easily be broken. Even though it’s illegal to steal, you can do it if you (ill-advisedly) decide to. But laws of nature, such as Newton’s laws of motion and the law of gravity, cannot be broken. You might see an advertisement for a product that includes the phrase “gravity-defying,” but it doesn’t really defy gravity; that would be impossible. (Airplanes and hot-air balloons do not defy gravity. There’s just another, upward force that’s at least as strong.)

**“HYPOTHESIS”**

The general public might think of a hypothesis as a guess, but people will more commonly use the unscientific version of the word *theory* for this. In school science lessons, many students are, unfortunately, taught that a hypothesis is a guess—or “educated guess”—at the outcome of an experiment. But that’s not how actual scientists use the term. In most of physical science, a hypothesis is a tentative explanation for some observed phenomenon. Let’s see how this is different from a hypothesis as a guess.

Here’s an investigation you can have your students try. Give each pair or group of students a block of Styrofoam and an aluminum frying pan. (Perhaps some students can bring in frying pans from home.) Ask each student to place their hands on both objects and see how they feel as far as whether one feels warmer or cooler than the other. Interestingly, the aluminum frying pan will always feel cooler, even though both objects have been sitting out in the room, and therefore both are at the same temperature, i.e., room temperature.

Next raise the question: If we put an ice cube on each item—one on the Styrofoam and one on the aluminum, as in Figure 1—what will we observe? For example, will one melt faster than the other? What happens next is where the usual classroom or science fair approach differs from what scientists would do. Many teachers will tell students to make a prediction (or guess or educated guess) about what will happen and call that a “hypothesis.” Then the students will watch what happens and report whether the results agreed with their “hypotheses.”

The scientific approach, on the other hand, would be to watch the ice cubes melt, see that the one on the aluminum melts faster, and then try to explain *why*. The scientist might offer a possible explanation, and this is a hypothesis. Remember, a hypothesis is a possible explanation for some observed phenomenon. It’s not a guess at the outcome of an experiment, and it’s not an “if…then…” statement. Why doesn’t the scientist make a prediction about which ice cube will melt faster? Because she won’t learn anything by doing that. It’s because predictions like that are so useless that scientists usually don’t make them, and so they shouldn’t be a
required part of any science project.

A critically important aspect of hypotheses, which is not captured in the “guess” version, is how hypotheses are modified as new information is acquired and then the revised hypotheses are re-tested. This is exemplified by the following investigation, which you can also do with your students but preferably not in the winter. This will take 5 or 10 minutes or so, every hour in the morning and every half hour in the afternoon, except around lunch time. That might seem like a lot of time, but it’s only for one day. And if it’s too much time, you could have them do it only once an hour in the afternoon as well, in which case they’ll have fewer measurements from which to discern a pattern.

On a sunny day, starting first thing in the morning (e.g., 8:30 a.m.), have students go outside. They will work in pairs, and the students will measure the length of their partner’s shadow every hour until 11:30 a.m. They can list all the shadow lengths and if they are able (perhaps with your help), make a graph. Or you can make one graph on the board based on one student’s data. The list or graph will show how the shadow gets shorter and shorter as it gets later in the morning (see Figure 2).

Then discuss with the students what they could do with the data. What might a scientist do? One possibility that they might suggest—or you can guide them to—is to predict how the length of the shadow will continue to change for the rest of the day. There will probably be at least some students who will say, since the shadow has been getting shorter and shorter, that it will continue to do so for the rest of the day. Then, starting at 1:00 p.m., students can continue to make the measurements, this time every half hour (in order to get enough data before the school day ends). What they’ll discover is that, after 1:00 p.m., the shadow grows longer and longer—just the opposite of what was happening in the morning. In the “traditional school science” approach, students would note whether their prediction was correct, and that would be the end of it.

What would real scientists do (assuming they didn’t know why the shadow length was changing)? After the morning’s observations, the scientist would try to formulate a possible explanation (i.e., a hypothesis), which would explain why the shadow was getting shorter. Let’s say the hypothesis—a possible explanation—is that the Sun gets higher in the sky throughout the day. As the Sun gets higher, the length of the shadow will become shorter. (You can demonstrate this in the classroom with a light and a pencil. See Figure 3.) Then the scientist would want to test the hypothesis by looking at what it predicts. Well, if the Sun gets higher in the sky throughout the day, then this hypothesis predicts that the shadow should become shorter throughout the

![FIGURE 2](image-url)

A table and graph showing how the length of a shadow decreases as it gets later in the morning.

![FIGURE 3](image-url)

When the “sun” is low, shadows are long; when the “sun” is high, shadows are short.
day. (Notice that this prediction is a consequence of the hypothesis and is not a guess that the scientist pulled out of thin air.) So, to test the hypothesis, measurements are made in the afternoon to see whether the trend continues. The afternoon measurements show that the shadow is getting longer, not shorter as predicted. So now the scientist knows that there’s something wrong with the hypothesis, and it must be either discarded or revised. Important to note: Finding out that the hypothesis was wrong was a good thing; it enabled the scientist to learn something new! Perhaps the hypothesis will then be revised to correctly describe how the Sun rises in the morning, creating shorter and shorter shadows, and then gets lower in the afternoon, creating longer and longer shadows. This revised hypothesis is consistent with the observations, which now provide some supporting evidence for the hypothesis. (To see more about hypotheses, check out the article linked in the Online Resources below.)

The scientist could then go further and try to develop a theory that would explain why the Sun gets higher in the morning and lower in the afternoon. This theory might involve the rotation of the Earth.

The bottom line is that the investigator—the student-scientist—can do a much more thorough investigation—and learn a lot more—by not simply trying to predict the result of an experiment, but instead thinking in terms of explaining the observations. That’s much more like how real science occurs. And it’s a lot more interesting!

I’ll end with a quotation by Jules Verne from Journey to the Center of the Earth (1864).

“Science, my boy, is made up of mistakes, but they are mistakes which it is useful to make, because they lead little by little to the truth.”

Never stop learning.

ONLINE RESOURCES

Article on Hypotheses

Difference Between Theory and Law

Matt Bobrowsky is the lead author of the NSTA Press book series, Phenomenon-Based Learning: Using Physical Science Gadgets & Gizmos. You can let him know if there’s a science concept that you would like to hear more about. Contact him at: DrMatt@msb-science.com (hyphen required).